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ENGINEERING RELIABILITY APPLIED TO A LINE OF PACKING MACHINES

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Abstract. *This study aimed to analyze the reliability of equipment in a line of packaging machines from a company in the food sector. In this regard, a case study was carried out, where it was sought from the database, to detect the equipment and critical subsystems based on unscheduled stops. Weibull distribution function was used for probabilistic analysis using the Excel software. It was possible to state, through the application of Reliability Engineering, the premature failure behavior of the equipment and its components, and the critical subsystems that directly interfere in maintenance costs and times.*

Keywords: *Reliability Engineering, Weibull distribution, maintenance, packaging.*

1. INTRODUCTION

In the food sector, the packaging process of manufactured products represents a critical stage of production. In the manufacture of products in the form of powders such as flours, spices and pasta, this stage becomes more delicate due to the great tendency of failures and leaks, compromising quality, plant safety and productivity.

In this case, the behavior of equipment failures can become unpredictable, making maintenance planning difficult, and consequently causing significant production losses, as well as unforeseen maintenance costs.

In order to permit the prediction of the behavior of this type of process, the use of the equipment reliability analysis methodology becomes a strategic tool for maintenance management, allowing the forecast of the average time between stops, the risk analysis and facilitating the decision-making.

Combined with this method, it is possible to use other strategic maintenance management tools, such as Reliability Centered Maintenance (RCM), Failure Mode and Effect Analysis (FMEA), and failure tree analysis (FTA).

In this context, the aim of this work is to present a case study of a packaging line of powders products, using the reliability engineering technique for analyzing the performance of the equipment. After a more detailed study of the critical equipment of this line, the analysis of its failure tree will be carried out in order to identify the failure mechanisms of the equipment, aiming to seek an improvement of the components with less functional performance.

2. RELIABILITY ENGINEERING

Reliability Engineering is the study related to the probabilistic treatment of system failures. According to Hines et al (2006, p.151), "statistics works with the collection, presentation, analysis and use of data for solving problems, making decisions, developing estimates, planning and developing both products and procedures".

The use of Reliability Engineering allows the determination of the maintainability and availability of equipment and components during their operation, enabling optimized maintenance policies, ideal frequency for preventive interventions, determination of critical equipment and components, among others (Reliasoft Brasil apud Trindade, 2015).

Statistical analysis methods have been increasingly used to determine optimal maintenance periods and the number of spare parts required for an admitted risk, such as the use of normal, exponential and Weibull distributions.

The ABNT ISO / TR 10017 code establishes the use of appropriate statistical models to characterize variables of interest, such as time to failure or time between failures. The main functions used for the probabilistic analysis are presented below.

- a) Failure Density function $f(t)$: conceives the variation of the failure probability per unit of time.

$$f(t) = \frac{dF(t)}{dt}$$

Where $F(t)$ is the Cumulative Failure Function, which shows the probability of failure of a unit between a period of time t_1 and t_2 .

- b) Reliability Function $C(t)$: it is the probability of survival of an item in an established interval (of time, cycle, distance). That is, there will be no failure between the interval of 0 to t .

$$C(t) = 1 - F(t) = 1 - \int_0^t f(t)dt = \int_t^{+\infty} f(t)dt \quad (2)$$

Therefore, $F(t)$ can be called the Probability of System Failure.

2.1 Weibull distribution

The Weibull distribution has been widely used to represent the time of failure, being able to come close to the observed phenomenon, providing a great approximation to the law of probability of random variables (Hines, 2006).

According to Oliveira (2014), Weibull analysis is particularly recommended to systems that contain components in line, where the failure of a component causes the entire system stop. For Fogliatto et al (2009), the Weibull distribution is suitable for modeling time to failure with constant, increasing or decreasing risk functions. He also highlights the importance of this distribution due to the flexibility and the ability to model the time to failure with different behaviors, assuming the types of normal distribution (increasing failure rate), exponential distribution (constant failure rate), and distributions with decreasing failure rates.

According to Oliveira (2014), the Weibull $f(t)$ distribution is given by the following equation:

$$f(t; \beta, \eta, \gamma) = \frac{\beta}{\eta} \left(\frac{t - \gamma}{\eta} \right)^{\beta-1} e^{-\left(\frac{t - \gamma}{\eta} \right)^\beta} \quad (3)$$

for $t \geq \gamma$ and $f(t; \beta, \eta) = 0$ for $t < \gamma$

where:

- The scale parameter (η) refers to the life of a component, outlining and simulating a distance, time or cycles elapsed from the beginning of the activity to the failure;
- The location parameter (γ) is considered representative of the initial life of the component under study, so a null value is assigned when it is a new component;
- The non-dimensional shape parameter (β) modifies the shape of the probability density function of a system where infant mortality, maturity and senile mortality occur. Therefore, its value defines whether the risk of equipment failure is constant, increasing or decreasing (Mengue & Sellitto, 2013).

For the purposes of graphical representation, from mathematical manipulations using a logarithmic scale, it is possible to rewrite Equation (3) through the equation:

$$\ln(-\ln(1 - F(x))) = \beta \cdot \ln(x) + \beta \cdot \ln(\eta) \quad (4)$$

That can be represented (simplified) in the form of a line equation by:

$$Y(x) = m \cdot \ln(x) + c \quad (5)$$

where $Y(x) = \ln(-\ln(1 - F(x)))$, $m = \beta$ and $c = \beta \cdot \ln(\eta)$.

To obtain the parameters of the m and c line of equation [5], a linear regression method can be used, which allows to obtain the shape β and scale η parameters. Different techniques can be used to work on the data to be analyzed and to obtain the cumulative distribution function $F(x)$, being common the use of statistical software that offers algorithms to facilitate the procedure.

2.2 Failure Tree Analysis

Failure Tree Analysis (FTA) is a deductive technique in which a system or event is analyzed using Boolean logic to establish the combinations of failures and conditions that could cause the event (ABNT, 2012). In reliability and safety

engineering, it is used as a tool to understand why the system fails, what are the main risks and the sequence of events associated with the failure.

The technique consists of building a flowchart, starting from the main event, and identifying the subsequent levels of events or failures that may cause the main event. This method is described in several Standards. The present paper based on the ISO/ABNT code IEC 31010-2012: Risk management - techniques for the risk assessment process ("IEC 31010-2012: Gestão de riscos - Técnicas para o processo de avaliação de riscos").

3. MATERIALS AND METHODS

To carry out this study, data related to the maintenance activities of a packaging line of products in powder form for the food sector were used. The line in question was composed of 15 machines with the capacity of packaging between 10g to 250g. Due to confidentiality, data relating to the company, such as name and location, and about the production line, such as information on the model and brand of equipment, will be kept confidential.

The database provided the following information: a) equipment code; b) date and time of the interventions; c) type of maintenance; d) duration; e) cause of failure; f) corrective action. The database used contained information on occurrences of thirty days of operation, in the period between 01/01/19 to 01/30/19, with the machines operating in three shifts, totalizing 10,800 hours of operation. Microsoft Excel V.2016 was used for the analysis and statistical treatment of the data.

Figure 1 shows the main steps taken in the present work. In the data pre-analysis stage, corrections were made in the database, due to inconsistent information and imputed errors. In step three, equipment was classified based on the number and duration of maintenance events. From this study, the critical equipment for the study of reliability was selected. In step four, the study of probability of failure was carried out, in order to assess its reliability. In step five, a fault tree analysis of the components with the highest frequency of failures was performed.

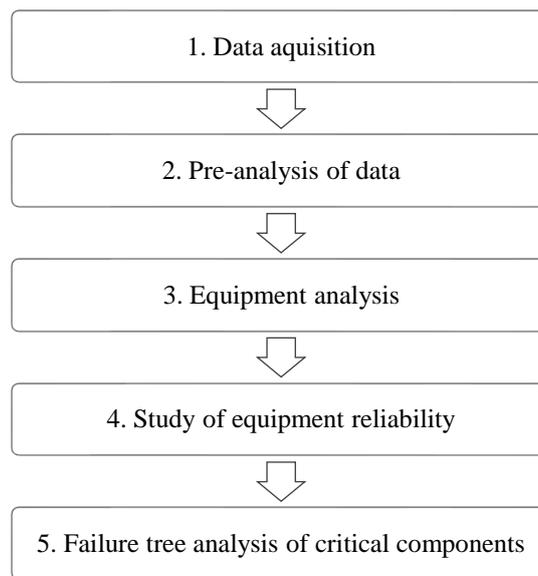


Figure 1. Step's flowchart

4. RESULTS

Figure 2 shows the graph of the hours of corrective maintenance per equipment during the analyzed period. As shown, machine 01 had a greater contribution, being responsible for 14% of maintenance events on the line. Therefore, this equipment was the first selected to carry out the reliability study, and due to the similarity of the results obtained in the other equipment, only the analysis of machine 01 will be presented in this work.

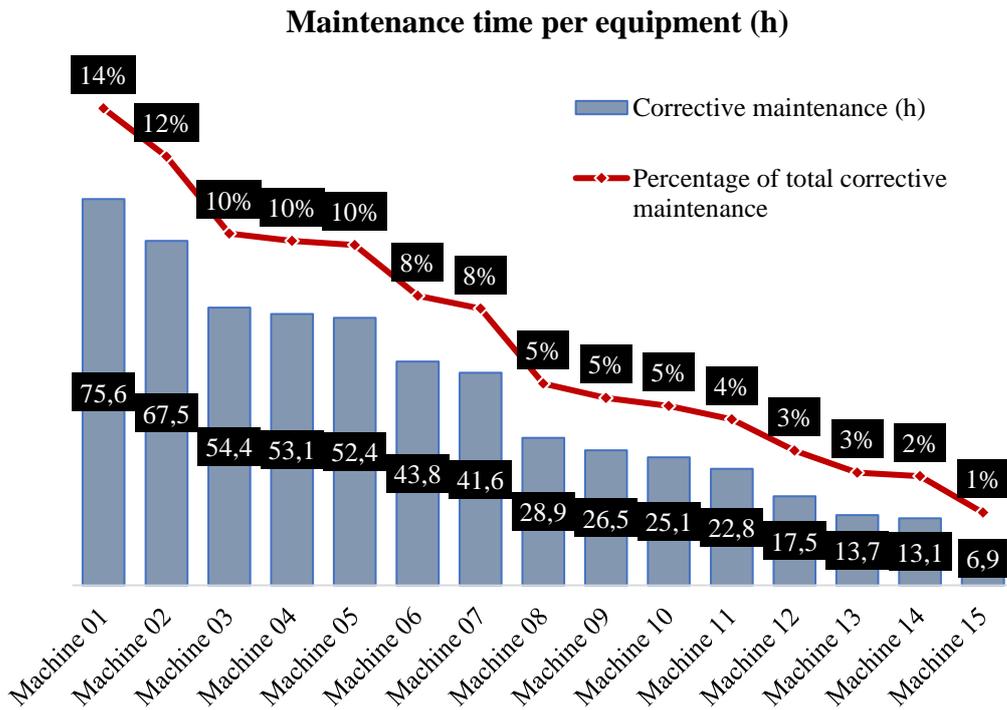


Figure 2 – Hours of corrective maintenance by equipment.

Figure 3 shows the Weibull distribution for machine 01. The chart was obtained from the plot of 88 maintenance events for this equipment in the period analyzed, summing 75.6 hours of corrective work. For the plotting of the chart, Equation (4) was used, where it is observed that both the x and y axes are on a logarithmic scale.

Using the trend line feature on Excel software, it was possible to obtain the equation that represents the Weibull distribution function, including the parameters β and η which are equivalent to 0.8646 and 330min, respectively. Note that the coefficient of determination of the linear regression function is 95.95%, with a greater deviation in the initial x values of the chart (within 1.8 to 3.8).

Figure 4 presents the machine 01 reliability chart, where an exponentially shaped curve is observed, with a remarkable drop in reliability on the initial operating time range. Considering the sample range (corrective stops between 0 and 2,000 minutes), it's observed a drop of 80% in the equipment reliability for the elapsed time of 600 minutes.

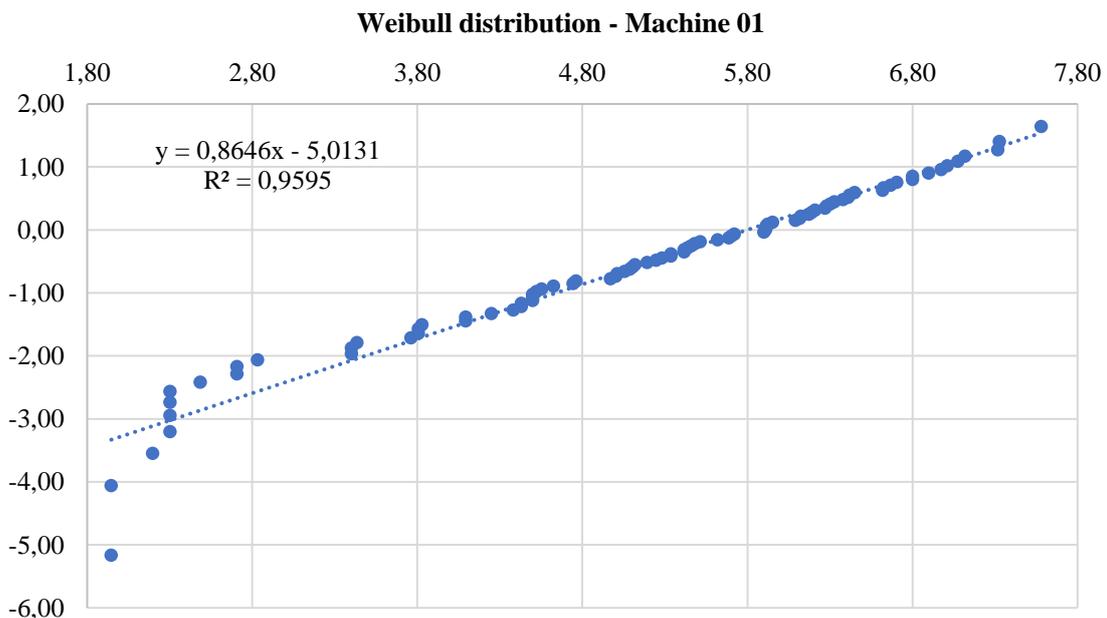


Figure 3 - Weibull graphical distribution: $\beta = 0,8646$ and $\eta = 330\text{min}$. $R^2 = 0,9595$.

Reliability - Machine 01

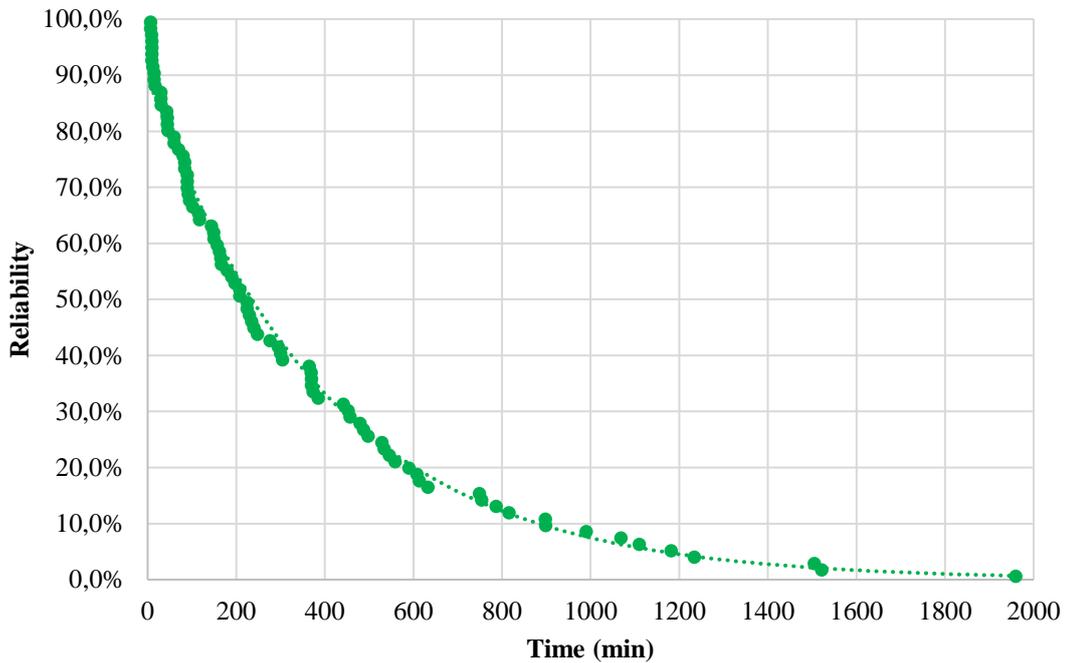


Figure 4 – Reliability vs. Time chart (min) - Machine 01.

This behavior can also be observed in Figure 5, which presents the chart of the probability function of cumulative failure, which according to the literature, is showing a characteristic behavior of premature failure of the components.

Probability function of cumulative failure - Machine 01

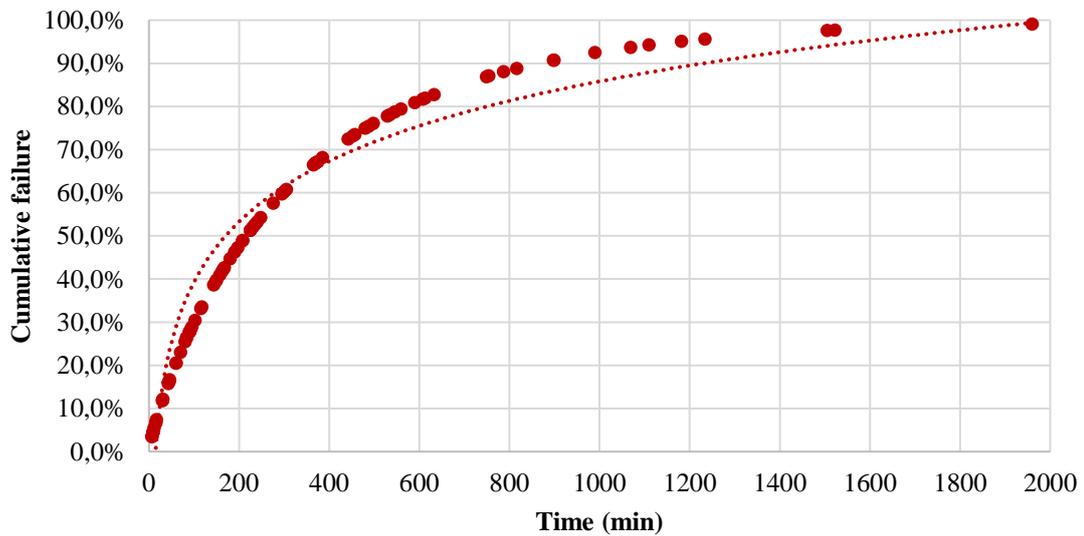


Figure 5 - Cumulative failure probability function - Machine 01.

From the result of premature failure found in the equipment, a study of the types and cause of the failures was developed. Figure 6 shows a Pareto chart with the maintenance hours due to failure, and the pie chart showing the type of failure (mechanical or electrical). It is observed that 69% of the failures occur due to four causes, which are: a) failure of weld 1, b) failure on the photocell, c) failure of weld 2 and d) failure of regulation.

Maintenance hours by failure mode - Machine 01

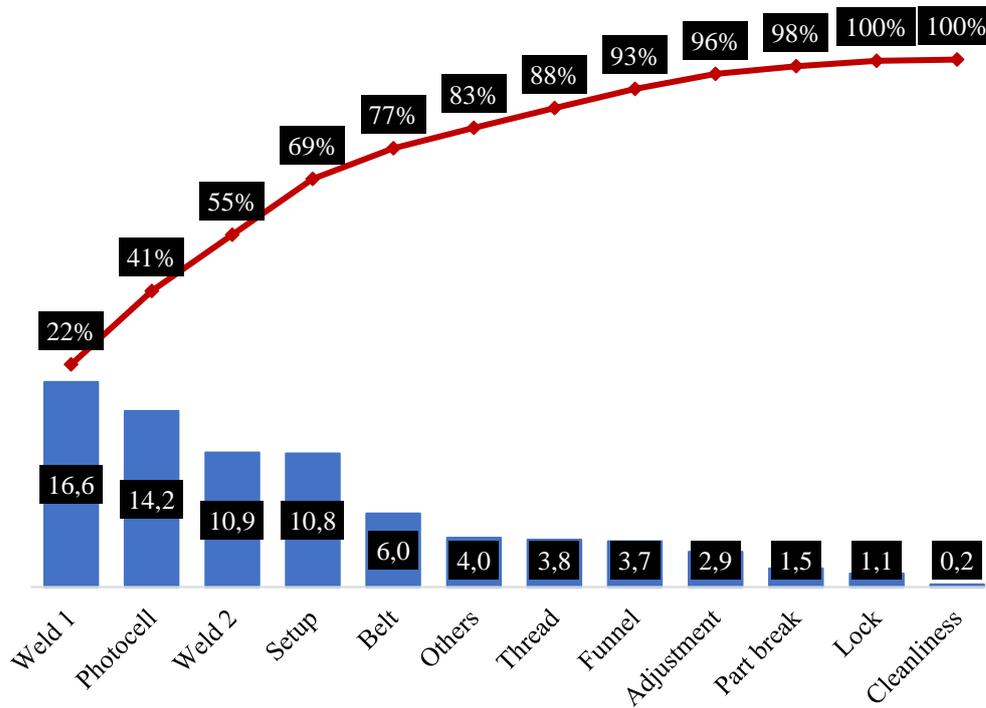


Figure 6 – Pareto’s chart of failure modes - Machine 01.

In order to work on the optimization and reduction of maintenance costs of this equipment, a fault tree analysis was performed on the four main failure modes responsible for 69% of the corrective maintenance events of this equipment. The following figure shows the analysis of the machine 01 fault tree.

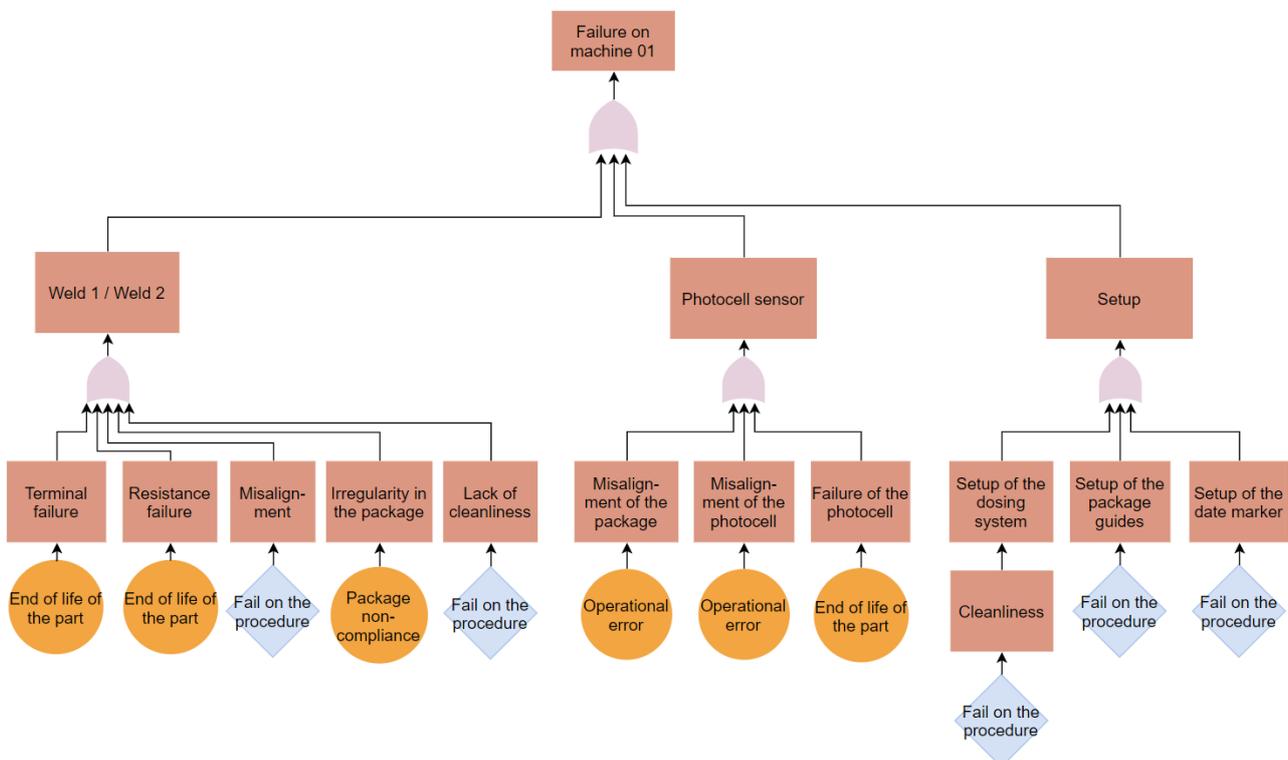


Figure 7 – Failure tree analysis of machine 01.

As can be seen from the fault tree, the main basic events responsible for the occurrence of corrective maintenance of equipment 01 are:

- End of component life;
- Failure on the procedure (daily checklist);
- Non-compliance of the package;
- Operational error.

Based on this analysis, an action plan is being conducted to control each of these factors in order to mitigate or eliminate the occurrence of these failures, thus reducing the occurrences of unforeseen corrective maintenance. Concerning the end of the component life, a reliability study was conducted to determine the ideal MTBM (Mean Time Between Maintenance) of these parts, in order to determine their replacement on the preventive maintenance event.

5. CONCLUSIONS

The present work aimed to evaluate the reliability of a line of packaging machines from a large company in the food sector. Due to confidentiality, data relating to the company and the equipment were kept confidential.

From the data provided by the company, it was possible to classify the equipment with the greatest relevance in terms of events of corrective maintenance, and from this, elaborate a study of its reliability using probabilistic failure methods by reliability engineering. Weibull distribution was applied using the Excel V.2016 software, and the results of critical equipment were presented, where it was observed:

- Adherence of the maintenance data supplied with the Weibull distribution model used in the analysis;
- It was possible to obtain the parameters of the failure probability function ($\beta = 0.8646$ and $\eta = 330\text{min}$), with a coefficient of determination of 95.95%;
- The equipment reliability and probability failure charts presented an exponential shaped curve, characterized by premature failure behavior (decreasing failure density rate);
- The four main causes of failure are responsible for 69% of the interventions, which requires sequential studies to optimize these components and reduce equipment maintenance costs and times.
- The fault tree analysis was used to study the root causes and relationships between the main modes of failure of the equipment called machine 01.

Based on the results and premature failure behavior observed, a plan of actions is being carried out to work on the four main root causes of failure to reduce the high rate of unplanned corrective maintenance events.

6. ACKNOWLEDGEMENTS

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